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Policy plan for the use of biomass and biofuels in Greece Part II: Logistics and economic investigation

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Abstract

The introduction of biomass driven energy products like bioethanol, biodiesel, Combined Heat and Power production or solid biofuels is vital for achieving the targets set from the EU for the year 2010 (20% electricity production from RES). However, in order to reach these targets, a policy plan has to be formed concerning the conversion of biomass. The aim of this paper is to examine the logistics involved in the exploitation of already available or new biomass resources and to analyse various scenarios for the economic feasibility of the use of biomass and biofuels in Greece.

Keywords: Energy crops; Bioethanol; Biodiesel; Pellets; Bioconversion costs

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1. Introduction

In order to introduce a policy plan in a country like Greece, in which biomass can play a significant role for the achievement of the 2010 aims set by the EU directives, an economic analysis is vital. The aim of this paper is to examine the investment and operating costs of various technologies employed in the units of energy conversion of biomass into final products. More precisely, the production cost of primary sources as well as subjects related to the functionality and the cost of the supply chain of primary sources (logistics) are going to be considered.

Issues concerning the final disposition of the liquid and solid biofuels are also considered alongside the economic viability of the units.

2. The production cost of primary sources

2.1. Data for the production cost of primary sources

One of the most important parameters that indicate the viability of the units that convert primary biomass into final energy products is the procurement cost of primary sources at the gate of these units. This cost consists of the following parts:

- the production cost of primary sources;
- the pre-treatment cost, either in their production area (e.g. chipping) in which case the cost is added to the procurement cost, or in the conversion unit (e.g. drying), in which case it is part of the general operating cost of the plant;
- the transportation cost of primary sources to the conversion unit;
- the profit of the primary source producer and the transporter.

The production cost of primary sources has to be separated taking into account the fact that biomass may be already available (like for example the agricultural residues of the olive oil cultivation sector, or the sub-products of a specific production process, e.g. wood industry residues, or second generation fuels and organic waste), or new (energy crops).

In this study, only the procurement cost of primary sources for energy corps will be examined, since the cost of already available biomass is linked with fuel availability studies.

Finally it is assumed, that farmers are responsible for both production and transportation of primary sources to the conversion plants. This way the producer is the transporter and the profit of the producer is calculated for both the production and the transportation to the plants.

2.2. Production cost of energy crops

The main energy crops that will be discussed in this study are the following:

- rapeseed (*Brassica napus*) and sunflower for biodiesel production (in this study, sunflower will be exclusively researched, since it is an already known cultivation to Greek farmers);
- sweet sorghum for bioethanol production (comparison with the already available relative cultivations);
- fiber sorghum for electricity production or for the production of modified fuels (pellets and brickets).

According to data provided by the Center for Renewable Energy Sources (CRES) [1], the production cost and the economic analysis of energy crops for biodiesel and bioethanol production in Greece are presented in Tables 1 and 2.

This data is also based on the 1st annual Report of the Greek Ministry of Development [2].

More recent references [3] raise the total production cost of sweet sorghum up to €≈17 tonne^{-1} or, with an efficiency of

Table 1
Production cost and economic analysis of energy crops for biodiesel production [1]

Data	Rapeseed		Sunflower	
	Irrigated	Dry	Irrigated	Dry
Efficiencies (kg/1000 m^2)	300	180	300	175
Cost (€/tonne)	400	400	250	250
Gross income (€/1000 m^2)	120	72	75	43.75
Field rent	28.50	12.00	28.50	12.00
Ploughing	9.00	9.00	9.00	9.00
Field preparation	10.00	10.00	5.00	5.00
Fertilizing	29.32	29.32	4.00	4.00
Sowing	13.20	13.20	8.40	8.40
Weed killing	9.20	9.20	4.60	4.60
Hoeing	6.20	6.20	6.20	6.20
Irrigation	10.00		10.00	
Harvesting	9.00	9.00	9.00	9.00
Production cost (€/1000 m^2)	124.42	97.92	84.69	58.19
Profit without subsidies (€/1000 m^2)	−4.42	−25.92	−9.69	−14.44
Subsidies (€/1000 m^2)	29.39	29.39	29.39	29.39
Profit without taxes and interest (€/1000 m^2)	24.97	3.47	19.70	14.95

Table 2
Production cost and economic analysis of energy crops for bioethanol production [1]

Data	Grain		Sweet sorghum	Beet	Corn
	Irrigated	Dry			
Efficiencies (kg/1000 m^2)	550	300	7000	6700	1172
Price (€/tonne)	130	130	20	50	132
Gross income (€/1000 m^2)	71.5	39	140	335	154.7
Field rent	28.5	12	28.5	35	28.5
Ploughing	9	9	9	12.61	9
Field preparation			10	9.03	10
Fertilizing	14.4	14.4	10.8	33.45	34.3
Sowing	11.76	11.76	9.2	16.8	20.62
Weed killing	10	10	8.1	31.96	8.1
Hoeing	6.2	6.2		53.95	20.1
Irrigation	10		30	33.47	31.18
Harvesting	9	9	17.4	46.65	17.4
Production cost (€/1000 m^2)	98.86	72.36	123.00	272.92	179.20
Profit without subsidies (€/1000 m^2)	−27.36	−33.36	17.00	62.08	−24.50
Subsidies (€/1000 m^2)	51.05	51.05	26		59.02
Profit without taxes and interest (€/1000 m^2)	23.69	17.69	43.00	62.08	34.52

8 tonnes/1000 m^2, to €≈136/1000 m^2. Furthermore, concerning the production cost of sunflower, a slightly higher price of €86.80/1000 m^2 is presented in literature [3]. Finally, for the field efficiencies of sunflower seed, an average value of 350 kg/1000 m^2 may be used.

It is also remarked that nowadays, the price of sunflower (more specifically the price of its seeds) is showing a decreasing tendency. In the German market [4] a price range of €160–185 $tonne^{-1}$ can be found, when in Greece a range of €180–200 $tonne^{-1}$ is referred [3].

The production cost and the economic analysis of energy crops for the production of solid biomass (for electricity production or for the production of second generation biofuels in Greece) is presented in Table 3.

It has to be mentioned, that in the case of large scale introduction of biofuels in the energy balance of the European Union and in Greece, the above mentioned production costs (€/tonne of primary sources) are expected to reduce significantly, since the cultivation efficiencies of energy crops will increase. As a comparison, it can be mentioned that the efficiencies of corn cultivation in USA has increased about 300% in 30 years [5].

2.3. Pre-treatment cost of primary sources (upstream conversion plant)

The chipping of primary sources in the field and the production of chips is a very important and vital method for the

Table 3
Production cost and economic analysis of energy crops for the production of solid biomass [1]

	Fiber sorghum	Cynara cardunculus (dry)
Income of the producers		
Efficiencies (tonnes/1000 m^2)	5.50	1.25
Selling price (€/tonne)	20.00	30.00
Subsidies (€/1000 m^2)	26.02	29.39
Gross income (€/1000 m^2)	136.02	66.89
Cost parts		
Field rent (€/1000 m^2)	35.00 (28.0%)	9.00 (15.7%)
Primary sources (€/1000 m^2)	17.96 (14.0%)	0.0 (0.0%)
Cultivation interferences (€/1000 m^2)	72.84 (58.0%)	48.26 (84.3%)
Total (€/1000 m^2)	125.80 (100.0%)	57.26 (100.0%)
Production cost (€/tonne)	22.87	45.81
Producers' profit		
Profit without taxes and interest (€/1000 m^2)	10.22	9.63
Profit without taxes and interest (€/tonne)	1.86	7.70

management and the pre-treatment of most of the primary sources for the following reasons:

- It increases significantly the Specific Gravity of the transported material, from 75 to 125 kg/m^3 for woody biomass (e.g. sweet and fiber Sorghum, corn, etc.), up to 300 to 350 kg/m^3 for chips (there is an increase in the energy density of primary sources of ≈200%) and, consequently, that leads to a more economical and environmentally advantageous transportation of chips into the conversion plants.
- The treatment of chips at the conversion plants (storage, transportation, feeding into other conversion units in order to improve the physical–chemical properties of biomass, e.g. drying) is much easier than that of the non-pre-treated biomass.

The cost of biomass chipping is a function of various parameters, the most important of which is the potential of the needed instrumentation. It is estimated that the cost of chipping for energy crops (all year-round treatment) is about €4–6 dry $tonne^{-1}$ [6].

2.4. Transportation cost of primary sources

Primary sources (various biomass types), after having been collected in central collection points, they are being transported with trucks to the conversion plants. The transportation cost of primary sources depends on many factors. In the case in which biomass transport is done with trucks which cover short distances to the plant (e.g. from a radius of around 30 km), the cost is estimated according to the following assumptions:

- average distance of the conversion plant from the biomass production area: 30 km;
- distance covered by the truck: (2 × 30) = 60 km;
- mean velocity of the truck: 40 km/h;
- duration of the truck service: (60/40) = 1.5 h;
- loading time of biomass in truck: 0.4 h;
- unloading time of biomass at the conversion plant: 0.1 h;
- total duration of a completed service: (1.5 + 0.4 + 0.1) = 2 h;
- number of services each day (for 8 h a day working time): (8/2) ≈ 4;
- mean load capacity of the trucks: 30 m^3.

Assuming the mean total day expenses (personal costs, consumables, using of the truck, etc.) of a truck at around €220 day^{-1}, the relative cost of transportation for every biomass type is provided from Eq. (1):

$$\frac{\text{total day expenses}\ (€)}{(\text{no. of services/day}) \times (\text{load capacity}) \times (\text{biomass specific gravity (S.G.)}) \times (100 - \text{moisture content\% (M.C.)})/100} \quad (1)$$

or

$$\frac{220}{4 \times 30 \times \text{S.G.} \times (100 - \text{M.C.\%})/100} = 1,833 \times \frac{100}{\text{S.G.} \times (100 - \text{M.C.\%})}\ (€/\text{dry kg})$$

The Specific Gravity (S.G.) and the Moisture Content (M.C.) for given biomass types is presented in Table 4. In the case of woody energy crops, the assumed S.G., after their chipping, is around 300 kg/m^3.

According to the above mentioned, the transportation cost of energy crops from their production area to the conversion plant is calculated in non-processed state (As Is = AI), as well as after their chipping, based on the data of Table 4 and Eq. (1) and is presented in Table 5.

As it can be seen from this data, the transportation cost of the non-pre-treated (non-chipped) primary sources to the conversion unit is very high, due to the initial low Specific Gravity of energy crops.

In the case of the chipping of primary sources in the field, there is a significant rise in energy density. In this case, the total chipping and transportation cost of chipped biomass, from the field into the conversion units is as low as 50% of the initial transportation cost.

3. Functionality of the supply chain

It is expected that if investment plans for energy exploitation of biomass are being realized (with energy crops or/and biomass residues as primary sources), large amount of biomass will be transported from their production field to the conversion plants where they will be converted into final energy products. Therefore, a systematic organization of the treatment of

Table 4
Specific Gravity (S.G.) and Moisture Content (M.C.) of various biomass types [7]

Biomass type	Moisture Content (weight%)	Specific Gravity (kg/m^3)
Biomass residues		
Olive tree pruning	35.00	300
Leaves–twigs (from olive oil production)	30.00	280
Olive pit	18.00	350
Vineyard pruning	37.00	325
Saw dust	65.00	450
Grain straw (in bales)	50.00	300
Energy crop		
Sweet sorghum (As Is)	40.00	100
Sweet sorghum (after chipping)	30.00	300
Rapeseeds (As Is)	50.00	125
Rapeseeds (after chipping)	40.00	300
Sunflower (As Is)	50.00	125
Sunflower (after chipping)	40.00	300
Fiber sorghum	40.00	100
Fiber sorghum (after chipping)	30.00	300

Table 5
Estimation of the total cost (a) of chipping of energy crops in the field and (b) of transportation of the chipped biomass in the conversion plant

Cost factor	Plant			
	Sweet sorghum	Rapeseed	Sunflower	Fiber sorghum
Transportation cost (without chipping)				
Specific cost (AI) (€/dry tonne)	30.56	29.33	29.33	26.19
Specific cost (AI) (€/tonne)	18.33	14.67	14.67	18.33
Pre-treatment of primary sources (biomass chipping)				
Chipping cost (€/dry tonne)	5.00	5.00	5.00	5.00
Chipping cost (€/dry tonne)	3.00	2.50	2.50	3.50
Transportation cost (of the chipped primary sources)				
Specific cost (€/tonne)	6.11	6.11	6.11	6.11
Total chipping and transportation cost (€/tonne)	9.11	8.61	8.61	9.61

primary sources is needed in order to reduce the pre-treatment cost and the transportation cost to these units.

Primary sources are possible to be delivered directly to the conversion units, collected from the producers that are in a range of 10 km. However, in the cases in which a large amount of fuel is needed to be treated, the complete organization of primary sources treatment is needed, in order to reduce the total pre-treatment (chipping) and transportation cost.

According to the literature, various organization schemes for biomass treatment have been proposed [8,9]. It is supposed that the producers of biomass from energy crops will be organized in a way to be responsible also for the transportation of primary sources into the conversion units, by creating Companies for the Treatment and Supplying of the Fuel (CTSF).

According to this data, the treatment equipment of primary biomass belongs to CTSF. So the producers, who constitute the CTSF, will be responsible for the total treatment of the fuel, from the production to the delivery at the gate of the plant.

Furthermore, a simple scheme of treatment and operation of the supply chain, as it may be undertaken by CTSF, is considered. This scheme refers to woody plants, like forestry, but also to energy crops like corn, sweet and fiber sorghum, etc. In a same way, it is possible to treat several agricultural residues like for example olive tree pruning [10].

According to the given treating scheme, special mow-thresh machines are used to mow primary sources, in order to collect them in the side of the field and, successively, they are chipped from moving chippers.

The chips are loaded to containers, which are driven (in a group of two or three containers) for long distances (20–50 km) by using trucks of the conversion plant.

Consequently, the treatment of the produced primary biomass needs the following equipment:

(a) mow-thresh machines for the collection of cultivated biomass;
(b) moving chippers, or stable chippers (for larger biomass amounts) that will treat biomass in the field;
(c) containers, where the chipped biomass will be temporarily stored;
(d) trucks which transport the chipped biomass into the conversion plant.

The chippers follow a radial route, loading the containers in a way that in the end full loaded containers are provided to the trucks (Fig. 1).

Since biomass is chipped, it is transferred by open tipping trucks into the conversion plant. In the plant there are two (or more) unloading systems, so as to prevent delays during the unloading of the fuel, or problems concerning the fuel feeding in the case in which the sole system is damaged. The unloading points will include a ditch for the wheels of the trucks. The truck will be unloaded with hydraulic platforms which will be raised with an angle of 60° from the horizontal position.

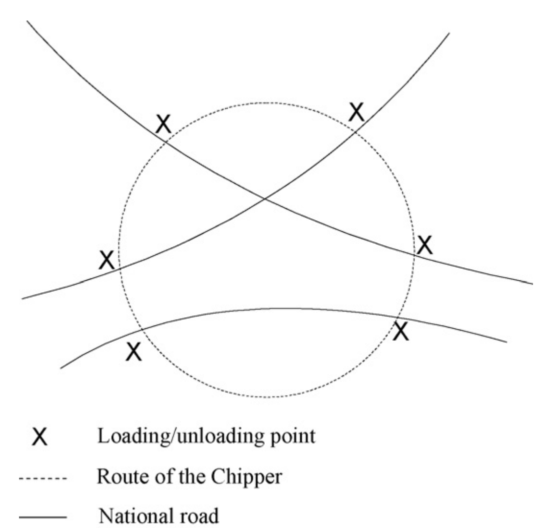


Fig. 1. Route of the moving chippers.

4. Transportation and final supply of liquid and solid biofuels

Biofuels should take profit of the already available installations and gradually replace conventional fuels (mainly diesel and gasoline), increasing also their percentage in the Greek energy market.

Examples of parallel use of biofuels and conventional fuels are known worldwide:

- In transportation (directly taken from the conversion plants). Use of biodiesel in already available gas stations (in separate tanks) in Austria, Germany and Sweden.
- In the transportation of solid biofuels (pellets) with suitable ships (dry load), or by means of railway net, from their production (in countries of high biomass potential, e.g. USA, Sweden, Canada, Russia, etc.) to central distribution stations (e.g. the port of Rotterdam) and then, by means of transportation companies, to final consumers.
- Transportation of the produced bioethanol, either directly to the refineries (where it is directly mixed with gasoline, providing the desired anti-knocking properties, or to gas stations where it is provided to the consumers as E85 (mixture of 85% Ethanol, 10–15% Gasoline and 5–0% additives), or as E95 (mixture of 95% Ethanol and 5% additives).

In special studies made in USA [11] the needed installations for the transportation and delivery of bioethanol in various levels is discussed. More specifically it is referred that for a low penetration scenario that corresponds to the total ethanol production in USA of around 19.3×10^9 l/year, around 500 terminals and 35,000 points of delivery are needed, with a total investment cost of €≈240 mil or, in reference to a mixture of 85% Ethanol and 15% Gasoline (E85) to €0.02 l^{-1}.

It must be also underlined that bioethanol is transported (in Brazil and South Africa) also by means of pipes. However in USA and in EU this would be only achievable if the transported bioethanol volumes reached the 40% of the totally transported gasoline.

Finally it should be pointed out that the delivery and transportation of liquid and solid biofuels has started the last years, so there is a high improving potential and cost efficient planning.

5. Evaluation of investment and operating cost of the conversion units of primary biomass to final energy products

5.1. Small plants for the production of solid, second generation fuels (pellets/brickets)

The investment cost of a "small" Treatment and Conversion Unit (TCU) of yearly potential of ≈6000 tonnes of pellets is estimated at around €625,000. Primary sources for the feeding of the TCU are mainly biomass residues (from agricultural and industrial activities) and also energy crops like for example fiber sorghum. The small TCU, which mainly has a local character, concentrates the biomass residues of a small specific area and has an efficiency of around 41%. This efficiency is defined as the percentage of primary biomass which is converted to final product-pellets. For such efficiency, the yearly biomass feeding should be as high as 14,500 tonnes. The total operating cost (TOC) of the above unit is divided as shown in Table 6.

Table 6
Operating cost of a TCU for a yearly potential of 6000 tonnes pellets [12]

#	Operating cost category	%	€/year
A	Personnel	13.20%	95,200
B	Operating and maintenance	1.34%	9,650
C-1	Consumption of electrical power	10.95%	78,986
C-2	Fuel (diesel) consumption	2.08%	15,000
D	General expenses	0.66%	4,760
E	Consumables	1.46%	10,500
F-1	Production cost of primary sources (biomass)[a]	40.42%	291,436
F-2	Transportation cost of primary sources (biomass)[b]	19.42%	140,035
G	Other costs	1.48%	10,705
H	Rent	1.66%	12,000
I	Amortization	7.32%	52,745
	Total operating cost (TOC)	100.00%	721,017

[a] The production cost of primary sources at the gate of the unit is €≈20 tonne^{-1} (from biomass residues or energy crops, see Table 2).
[b] Transportation cost is €≈10 tonne^{-1} (see Table 5).

Regarding the data presented in Table 6, the total relative operating cost, minus the fuel cost (TROP − FC), for the above small unit ("small" TCU) is around:

$$\text{TROP} - \text{FC} = \frac{[721{,}017 - (291{,}436 + 140{,}035)]}{6000} = €48.25\ \text{tonne}^{-1}\ \text{of pellets}$$

This unit can treat biomass residues (e.g. pruning, residues from wood industry, etc.) and can be realized from single farmers, covering the local heat needs (by providing pellets).

5.2. Biodiesel production units

The capital cost of biomass-to-biodiesel plants, is mainly influenced by the plant size, since the technology is considered mature.

The Specific Investment Cost (SIC) for a typical biodiesel unit is referred [13] to be around €100 tonne^{-1} of annual potential. In Table 7, the investment cost for biodiesel production units is presented. With the exception of very small units, the economies-of-scale between "medium" plants (≈52,800 tonnes/year) and "large" plants (≈132,000 tonnes/year) are very low.

According to the operational programme "competitiveness" of the Greek Ministry of Development [15], the selected Investment Cost for a production unit with a capacity of 40,000 tonnes biodiesel/year, is €20,000,000 (it considers as SIC the price of €500 tonne^{-1}).

Table 7
Total Specific Investment Cost of biodiesel production plants as a function of their size [14]

Plant size (tonnes/year)	Low automation		High automation	
	Investment Cost (€)	Specific Investment Cost (€/tonne)	Investment Cost (€)	Specific Investment Cost (€/tonne)
3,520	1,500,000	374	2,440,945	610
52,800	7,480,315	124	12,440,945	207
132,000	15,511,811	103	25,926,771	172

Regarding the operating cost of biodiesel production, it is considered, first of all, that the primary sources cost represents usually the 60–80% of the Total Specific Operating Cost (TSOC expressed as €/l biodiesel) of these plants [16]. The economical feasibility of biodiesel plants is also linked with the selling possibility of glycerine which is provided as by-product. For a biodiesel plant of ≈150,000 tonnes/year capacity, the rest of the operating costs, except for the primary sources cost, represent a percentage of 7–15% of the TSOC.

An example of the cost of biodiesel production is provided at Table 8 which represents various scenarios for oil produced from oil containing seeds (rapeseeds are used as primary source).

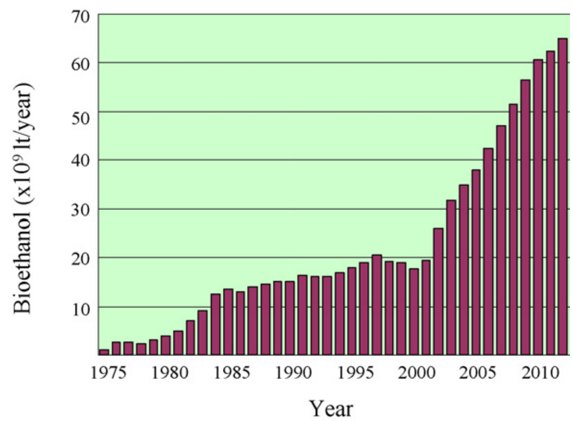


Fig. 2. Global bioethanol production.

5.3. Bioethanol plants

The total global bioethanol production (transportation fuel with a production as high as 40×10^9 l/year), is presented in Fig. 2 [18]. The main bioethanol producer country is Brazil (since 1976, the programme Proalcool is in operation).

The investment cost of bioethanol units is linked with many parameters the most significant of which are the following:

- the primary sources type and more specifically if they are:
  (a) saccharate primary sources (conventional, e.g. beet and sugar cane, or new, energy crops, e.g. sweet sorghum);
  (b) grains (wheat or corn);
  (c) or lignine-cellulosic primary sources (up to now the relevant technology is under investigation).
- the size of the plants and the possibility to achieve economies-of-scale;
- the possibility to use also other organic residues (e.g. the woody part of sweet sorghum or corn), for covering large energetic needs of the bioethanol production plant.

Some data of the Investment Cost for several plant sizes and various primary sources are presented in Table 9.

From the above mentioned data, a wide range concerning the SIC can be observed. This should not be normally expected, due to the fact that alcoholic fermentation is a mature technology. The high cost when using sweet sorghum is linked with the fact that also the technological risks are included when using this specific primary source. Furthermore, it should be mentioned that in the case of the specific plant, the realization of the whole production plant has been taken into consideration. This

Table 8
Biodiesel cost in Europe according to oil prices from rapeseed [17]

Scenario	Oil price (€/l)	Other production costs (€/l)	TSOC (€/l)
Small scale, high price	0.42	0.14	0.54
Small scale, low price	0.21	0.14	0.35
Large scale, high price	0.42	0.035	0.455
Large scale, low price	0.21	0.035	0.0245

Table 9
Capital cost data of bioethanol plants for several plant sizes and various primary sources

Plant size (tonnes/year)	Cost (€)	Specific Investment Cost (€/tonne)	Primary source	Reference
101,688	132,062,388	1354	Sweet Sorghum	[19]
152,500	184,000,000	1206	Corn	[20]
100,000	40,000,000	400	Grain	[21]

Table 10
Operating cost of bioethanol production for various primary sources

Plant size (tonnes/year)	Cost (€/l EtOH)	Primary sources cost (€/l EtOH)	Primary sources	Reference
101,688	0.28[a]	0.14	Sweet sorghum	[20]
<100,000	0.33–0.47	0.16–0.25	Corn	[22]
100,000	0.28–0.49	0.17–0.27	Grain	[22]

[a] This cost is referred to very large plants (>150,000 tonnes/year) and includes the selling of the by-products (Dried Distillers Grains with Solubles, DDGS).

includes also the additional investments (e.g. electricity production, cattle feed, pellets production, etc.).

The cost provided by GEA Wiegand is very low and eventually does not include these additional parts of the process (like for example the energy recovery part).

According to the operating programme "competitiveness" of the Greek Ministry of Development [15], the selected Investment Cost for a production unit with a capacity of 100,000 tonnes bioethanol/year, is €50,000,000 (it considers as SIC the price of €500 tonne^{-1}. That means that it is closer to the estimation of the company GEA Wiegand [21].

The operating cost of bioethanol production plants, is presented in Table 10.

The bioethanol production cost is, generally, higher in Europe than in USA. This is mainly due to the high production cost of primary sources in Europe, but also to the low energy cost in USA.

5.4. Power production plants from solid biomass

As presented by Boukis [12] the Specific Investment Cost for an electricity production unit of an installed capacity higher than 12 MW_e does not change significantly with the plant size. Therefore the Specific Investment Cost of these plants is well approximated to €≈1650 kW_e^{-1}.

The fuel cost at the gate of the unit has a share of about 37% of the total operating cost of the unit or 40% of the TOC if the annuity is not taken into consideration. These are the figures in the case of biomass feeding with residues. In the case of feeding of the plant with energy crops (fiber sorghum) it is expected that the fuel cost for the feeding of these plants (including the transportation and pre-treatment cost, according to Table 5) will be higher.

If the economies-of-scale are taken into consideration, the reduction of operating cost (apart from the fuel cost) is expected to be even higher.

5.5. Central Digestion Units

The total operating costs of Central Digestion Units of organic residues depends on their daily potential (organic waste input every day). For a unit of 150–200 tonnes/day (or ≈50,000 tonnes/year, for an availability of 90%), the TOC ranges between €2,500,000 and 5,000,000, depending on the type of the unit: Whether the unit is of agricultural type, low automation and provides the produced biogas to neighbouring exploitation units (this model is widely spread in Germany, Denmark and Sweden), or whether it has an autonomous and high automation electricity production system (if, for example, it is able to receive other organic waste).

The cost of the digestion units depends mainly on the operating and maintenance cost, which is usually presented as a percentage of the Investment Cost and ranges between 3 and 5% of this cost [23].

The feasibility of these units depends on the revenue coming from treatment of organic waste (minimization of the pollution) and, secondly, on the selling of the produced electricity and heat, but also on the provision of the compost.

6. Economic viability of the examined conversion plants and discussion about the profit of the farmers

The aim of this chapter is to describe the profitable investment plants for biomass conversion and to discuss the additional subsidy needed for the producers of primary biomass.

The results presented here are based on the methodology and the biomass data presented in the first part of this article.

More specifically, following data has been presented up to now:

(a) The needed cultivation areas and the types of energy crops that are expected to be exploited in order to reach the aims of Greece until 2010.
(b) An estimation concerning the technically usable biomass potential, when conventional cultivations are being replaced, has been done. The cultivation area for their production has been estimated, as well as typical size of units for the conversion of primary biomass into final products (liquid biofuels (biodiesel and bioethanol), electrical power, solid fuels (pellets)).
(c) Some specific areas in Greece have been detected, where it is technically possible to feed the conversion plants with the products of the relevant energy crops.
(d) The fluctuation of the range of investment and operating cost for typical sizes of biomass conversion plants has been discussed.

Two main conditions are needed for the viability of bioconversion projects and concern both sides, first of all the investors (responsible for the realization and the operation of the bioconversion units) and the farmers-producers (providers of the primary sources in the conversion units):

(a) The farmers should at least retain their net profit at the same level as it is nowadays with conventional cultivations, if they replace them with energy crops.

(b) The investors should have a minimum percentage of profit, which is expressed with the Internal Rate of Return (IRR) and is set equal to 15%.

6.1. Methodology for the calculation of the Net Future Profit (NFP) for the farmers-producers

For the calculation of the Net Future Profit of the farmers-producers, after the introduction of energy crops, which can replace conventional (traditional) cultivations, two figures have to be calculated:

- the production cost of primary sources, both for energy crops and conventional cultivations;
- the present and future total subsidies for conventional and energy crops cultivations respectively.

For the calculation of the production cost of primary sources and the needed subsidy to the farmers the methodology which can be used is described as follows:

Following parameters are set:

A: The purchasing cost of the primary source (€/1000 m^2), which corresponds to the Maximum Acceptable Purchasing Fuel Price (MAPFP, see D) of this specific primary source.
B: The field efficiency of the primary source (tonnes/1000 m^2).
C: The transportation cost of the primary source (€/tonne).
α%: The percentage of the primary source losses in the supply chain (assumption: a quantity of $2\alpha/3$ is lost in the field during mowing/collection and chipping and $\alpha/3$ is lost during transportation).
D: The Maximum Acceptable Purchasing Fuel Price (MAPFP) of the primary source in the gate of the bioconversion unit.

All calculations are referred to 1 tonne of primary source (energy crop) produced in the field.

Therefore:

- 1 tonne in the field costs: (A/B) (€);
- the transportation costs: C (€/tonne) $\times$ 1 tonne $\times$ $(1 - 2\alpha/3) = (1 - 2\alpha/3)C$ (€);
- the final cost up to the gate of the plant is: $(A/B) + (1 - 2\alpha/3)C$ (€);
- the final purchasing cost at the gate of the plant (€/tonne) is calculated from Eq. (2):

$$D = \frac{(A/B) + (1 - 2\alpha/3)C}{1 - \alpha} \tag{2}$$

The relation between the primary source production in the field and the MAPFP is provided using Eq. (3):

$$A = \left[\left[(1 - \alpha)D - \left(1 - \frac{2\alpha}{3}\right)C\right]\right] \times B \tag{3}$$

Taken into consideration that the efficiency of the supply chain is around 70% ($\alpha = 30\%$), Eq. (3) can be written as follows:

$$A = [0.7 \times D - 0.8 \times C] \times B \tag{4}$$

Some further parameters needed are:

RC_{conv}: The real cost of the conventional cultivation that is about to be replaced with energy crops (€/1000 m^2).
RC_{en}: The real production cost of the energy crop (€/1000 m^2).
E_{conv}: The present subsidy for the conventional cultivation (€/1000 m^2).
E_{en}: The needed subsidy for the energy crops cultivation, in order to ensure the same profit for the farmer as the one he has with the present conventional cultivations (€/1000 m^2).
H: The present selling price of the conventional cultivation in the delivery point (€/tonne).
I: The area efficiency of the conventional cultivation (tonne/1000 m^2).
β%: The losses of the product in the conventional cultivation at the supply chain ($\beta \approx 20\%$).

Using these parameters, the Net Present Profit (NPP) and the Net Future Profit of the farmer are calculated as follows:

$$\text{NPP} = E_{conv} + H \times I \times (1 - \beta) - RC_{conv} \tag{5}$$

$$\text{NFP} = E_{en} + (A - RC_{en}) \tag{6}$$

As discussed before the two profits have to be at least equal (NPP = NFP), therefore, the additional needed subsidy (differ-

Table 11
Efficiencies, costs and subsidies of the conventional cultivations [24]

Conventional cultivations	I (tonnes/1000 m^2)	H (€/tonne)	RC_{conv} (€/1000 m^2)	E_{conv} (€/1000 m^2)
Soft wheat	0.260	155.00	85.00	15.56
Hard wheat	0.250	155.00	85.00	48.86
Tobacco	0.350	550.00	1075.00	890.00
Cotton	0.350	320.00	200.00	146.00
Corn	0.900	132.06	165.00	51.28
Beet	6.250	26.99	190.00	47.00

Table 12
Efficiencies, costs and needed subsidies for energy crops

Energy crops	C[c] (€/tonne)	B[d] (tonnes/1000 m^2)	RC_{en}[e] (€/1000 m^2)	D[f] (€/tonne)	E_{en}[g] (€/1000 m^2)
Fiber sorghum[a]	9.61	3.71	125.80	26.77	82.23
Sweet sorghum	9.11	8.00	136.00	25.00	51.78
Sunflower	8.61	0.35	86.80	187.41	40.77
Fiber sorghum[b]	9.61	3.71	125.80	46.03	16.05

[a] Fiber sorghum for electricity production units.
[b] Fiber sorghum for biomass treatment and conversion units.
[c] Data from Table 5.
[d] Data as discussed in Section 2.2 [3].
[e] Data from Tables 2 and 3.
[f] These figures will be discussed in Sections 6.2–6.5.
[g] These figures will be discussed in Sections 6.2–6.5.

ential subsidy) is calculated from Eq. (7)

$$\Delta E = E_{en} - E_{conv} = -(RC_{conv} - RC_{en}) + (1 - 0.2) \times (H \times I) - A \quad (7)$$

The production costs taking into consideration the present subsidies are presented in Tables 11 and 12.

Given that for every conventional cultivation all the parameters of Eq. (7) are known, only the Maximum Acceptable Purchasing Fuel Price (MAPFP = D) is needed in order to calculate the "Energy crops" subsidy (E_{en}). This figure (MAPFP) is provided from the economic analysis of each conversion unit.

6.2. Fiber sorghum fired power unit (≈15 MW_e)

For a typical power unit (15 MW_e) with fiber sorghum as primary source, the main parameters concerning the fuel are presented in Table 13.

Table 13
Primary source availability parameters for a typical (≈15 MW_e) power plant

Parameter (unit)	Values
Efficiency of fiber sorghum (dry kg/1000 m^2/year)	2600
Lower heating value of fiber sorghum (MJ/dry kg)	17.9
Efficiency of the supply chain (%)	70
Size of a "typical" plant (MW_e)	15
Availability of the plant (%)	90
Net electrical efficiency (%)	22
Interconnection losses (%)	5
Net electrical energy production (MWh_e/year)	118,260
Net electrical energy provided (MWh_e/year)	112,347
Total yearly quantities of primary sources provided to the plant[a] (dry tonnes/year)	108,110
Humidity of fiber sorghum (%)	30
Total yearly primary sources quantities[b] (tonnes/year)	154,442
Total yearly primary sources quantities[b] (tonnes As Is/year)	220,632
Needed cultivation area (×1000 m^2)	59,401
Net energy efficiency of the cultivation (MWh_e/1000 m^2)	1.891
Specific energy efficiency of the cultivation[c] (MWh_e/dry tonne)	1.094

[a] It corresponds to the provided primary sources to the power unit for which the producer is paid from the investor.
[b] It corresponds to the produced biomass quantities from the producers and the totally cultivated surfaces of fiber sorghum (taking into consideration 70% efficiency of the supply chain).
[c] It corresponds to the energetic efficiency of the primary sources provided to the unit.

The total investment cost and the financing of the plant is presented in Table 14.

The operating cost for a 15 MW_e unit (excluding the fuel cost) is presented in Table 15 based on previous studies [25].

According to the Greek law (N. 3468/2006) the selling price of electricity to the net is €73 MWh_e^{-1}.

Using the above mentioned data, according to Eq. (4) and considering the minimum IRR of 15%, the MAPFP of this scenario is €25.44 $tonne^{-1}$.

In order to have a desirable economic efficiency, the purchasing cost of the fiber sorghum in the field cannot exceed the value of A = €37.60/1000 m^2.

Fig. 3 presents the viability of the specific investment plan.

Furthermore, according to the production cost of fiber sorghum (Table 3) and the conventional cultivations [24], the results provided by Eq. (7) are presented in Table 16.

In Table 16 it can be seen that the needed subsidy depends on the replaced conventional cultivation. It is also possible to calculate the differential subsidy ΔE, if a cultivation area of 59,401 × 1000 m^2 (see Table 13) is replaced. The results are presented in Table 17.

In Table 17 it can be seen that in order to retain their present profit, farmers should:

- get higher subsidy in the cases of soft and hard wheat, corn and beet;
- get lower subsidy in the cases in which tobacco or cotton cultivations are being replaced.

Finally, Fig. 4 shows the sensitivity analysis of the differential subsidy as a function of three parameters (efficiency

Table 14
Total investment cost of the fiber sorghum fired power plant

Parameter (unit)	Values
Specific Investment Cost (€/kW_e)	1,600
Unit size (kW_e)	15,000
Total investment cost (€)	24,000,000
Needed investment[a] (€)	6,000,000
Expected subsidy[b] (€)	9,600,000
Credit (€)	8,400,000

[a] 25% of the total investment cost.
[b] 40% of the total investment cost.

Table 15
Operating cost (without fuel cost) for typical power production plant

Operating cost parameter	€/year	€/kWh$_e$	%
1. Personnel	541,800	0.00482	27.94%
2. Operation and maintenance	480,123	0.00427	24.76%
3. Consumables	149,439	0.00133	7.71%
4. General costs	86,621	0.00077	4.47%
5. Ash treatment	40,865	0.00036	2.11%
6. Utilities	240,062	0.00213	12.38%
7. Other costs	153,891	0.00137	7.94%
8. Reciprocity fees	246,040	0.00219	12.69%
Total operating cost (without fuel cost)	1,938,841	0.01726	100.00%

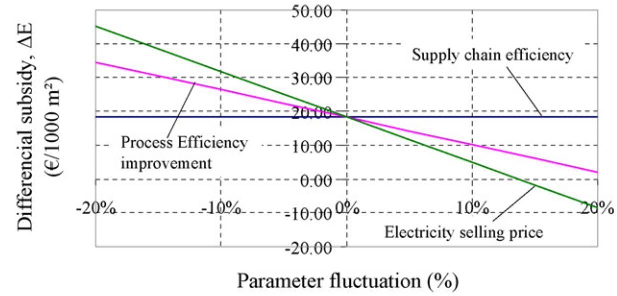


Fig. 4. Sensitivity analysis of the differential subsidy (ΔE).

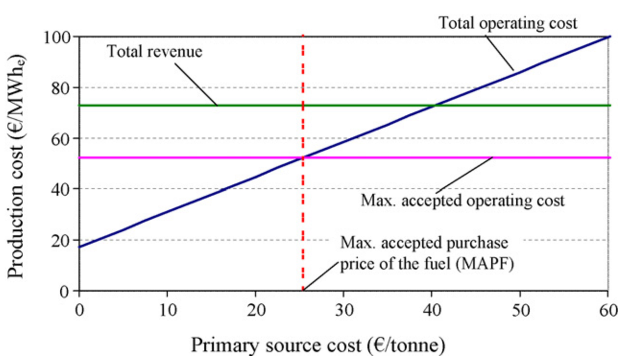


Fig. 3. Diagram of the viability of a power production plant.

of the supply chain, improvement of the efficiency of the power generation process, price of electricity sold to the net). From this figure it can be seen that, if the efficiency of the supply chain improves 10% (from 70 to 77%), the differential subsidy is practically constant at €18.29/1000 m^2. If there is a 10% rise of the selling price of electricity (from €73.00 to 80.30 MWh$_e$$^{-1}$), the needed differential subsidy is lower (from €18.29 to 4.96/1000 m^2).

Finally, if the efficiency of power generation is 10% higher (from 22 to 24.2% by using a more effective combustion chamber), the needed differential subsidy is lower (from €18.29 to 10.18/1000 m^2).

The improvement of the three parameters can reduce the needed differential subsidy to (0 + 13.33 + 8.11=)€21.44/1000 m^2. This subsidy can make the fiber sorghum fuelled power production plants feasible.

6.3. Bioethanol plant (150,000 tonnes/year) using sweet sorghum as primary source

For a typical plant of bioethanol production (capacity 150,000 tonnes/year) using sweet sorghum as primary source, the main parameters concerning the availability of primary source are presented in Table 18.

Table 16
Calculation of the needed subsidy, after replacing six conventional cultivations (for power production)

To be replaced	$RC_{conv} - RC_{en}$ (€/1000 m^2)	E_{conv} (€/1000 m^2)	$H \times I$ (€/1000 m^2)	E_{en} (€/1000 m^2)
Soft wheat	−26.94	17.61	46.20	40.46
Hard wheat	−26.94	49.89	41.25	68.78
Tobacco	524.20	1122.52	144.50	672.87
Cotton	74.20	146.00	108.00	117.15
Corn	53.39	49.89	158.47	82.23
Beet	147.10	47.00	205.38	23.15

Table 17
Calculation of the differential subsidy (ΔE) and the totally needed differential subsidy (ΔE_{tot}) for power production when replacing six conventional cultivations (for power production)

Cultivations to be replaced	Differential subsidy, ΔE (€/1000 m^2)	Total subsidy (€/year)		Totally needed differential subsidy, ΔE_{tot} (€/year)
		Conventional cultivations	Fiber sorghum	
Soft wheat	35.44	924,279	3,029,594	2,105,316
Hard wheat	34.20	2,902,330	4,933,988	2,031,659
Tobacco	−832.80	52,866,831	3,397,880	−49,468,951
Cotton	−22.20	8,672,536	7,353,982	−1,318,554
Corn	18.29	3,046,080	4,132,266	1,086,186
Beet	33.15	2,791,844	4,761,131	1,969,288

Table 18
Primary source availability for a typical bioethanol plant

Parameter (unit)	Values
Cultivation efficiency of sweet sorghum (tonnes/1000 m^2)	8.0
Efficiency of sweet sorghum to ethanol (lt EtOH/1000 m^2)	750.00
Supply chain efficiency (%)	70
Size of the typical unit (tonnes/year)	150,000
Total yearly quantities of primary sources provided to the unit[a] (tonnes As Is/year)	2,025,316
Total yearly quantities[b] (tonnes As Is/year)	2,893,309
Needed cultivation area[b] (×1000 m^2)	361,664
Area final efficiency (tonnes EtOH/1000 m^2/year)	0.41475

[a] It corresponds to the provided primary sources to the bioethanol unit for which producer is paid from the investor.
[b] It corresponds to the produced biomass quantities from the producers and the totally cultivated areas of sweet sorghum (taking into consideration 70% efficiency of the supply chain).

Table 19
Operating cost of a typical bioethanol plant

Operating cost parameter	€/year[a]	Fitting coefficient (%)	€/year[e]
Energy cost	9,282,000	200.00[b]	27,846,000
Cost of chemicals	5,893,333	100.00[c]	11,786,666
Other operating costs	9,810,667	10.87[d]	10,877,261
Total	24,986,000		50,509,927

[a] 2003 values.
[b] Taking into account the rise of the oil cost (3×) (US$/bbl) in 2006 in comparison to 2003.
[c] The oil cost provides an estimated 50% rise to the cost of chemicals.
[d] The yearly inflation is about 3.5%.
[e] 2006 values.

The investment cost of a typical bioethanol unit, according to the literature, is as follows:

- The Greek Ministry of Development [15] sets the specific cost equal to €500 tonne^{-1}, so the maximum selected cost of the unit should be (500 × 150,000=)€75,000,000.
- Tiffany and Eidman [26] set the investment cost of a bioethanol plant from corn, of similar capacity (154,379 tonnes/year) equal to US$ 78,000,000 (referred to the prices in 2003), therefore, the specific cost is US$ ≈0.4 l^{-1}. With a mean inflation of 3%, the specific cost is in 2006 US$ ≈0.44 l^{-1} or (€1 = US$ 1.25) €0.35 l^{-1}.
- The study of the European Beet Growers' Association [27], provides a specific cost of European bioethanol units of similar capacity (from ≈120,000 to 170,000 tonnes/year) at a price range of €0.4–0.8 l^{-1} (mean value €0.6 l^{-1}).

In the present study, as specific cost of a 150,000 tonnes/year bioethanol unit, the mean value of the USA (€0.35/l) and the EU (€0.6/l) will be used, after the addition of 15% due to the additional alterations and the longer time needed for the start of the unit to efficient production using sweet sorghum {(0.35 + 0.60)/2} × 115% ≈ €0.55 l^{-1} or (for a bioethanol density of 0.79 kg/l) €690 tonne^{-1}. Therefore the investment cost of a typical bioethanol unit is estimated at around €103,500,000.

The operating cost is presented in Table 19 based on data from Tiffany and Eidman [26].

According to the above, the Specific Operating Cost (SOC) excluding the Fuel Cost (FC) of a typical biomass is equal to:

$$SOC - FC = \frac{€50,509,927\ \text{year}^{-1}}{154,379\ \text{tonnes/year}} = €327\ \text{tonne}^{-1}\ \text{EtOH}$$

The transportation and pre-treatment cost of sweet sorghum is estimated at €9.11 tonne^{-1} (see Table 5).

According to the data of Elobeid and Tokgoz [28], the average selling price of bioethanol (according to USA and Brazil data) is about €500 tonne^{-1} and of DDGS is according Tiffany and Eidman [26] ≈€74 tonne^{-1} EtOH (the prices are related to 2006). According to the study CIBE [27] the average selling price of bioethanol in the European Union is estimated at around €700 tonne^{-1}. For secure calculations, the selling price of bioethanol in the present study is considered to be €650 tonne^{-1}.

The above data is inserted to a typical economic model where it is calculated that the MAPFP in this scenario is equal to €24.40 tonne^{-1}. The viability of the specific investment plan is presented in Fig. 5.

Since MAPFP is calculated and considering the efficiency data (Table 2) and the transportation cost of sweet sorghum (Table 5), it is calculated that, according to Eq. (4) in order to have an IRR = 15%, the procurement cost of sweet sorghum from the field cannot exceed the price of A = €78.33/1000 m^2.

Based on the data for the production of sweet sorghum (Table 2) and the cultivations to be replaced (Table 11) the needed subsidy (E_{en}) is calculated from Eq. (7) and presented in Table 20.

In Table 20 it can be seen that the needed subsidy is lower than the present one in the cases of tobacco, cotton and corn and higher for the other cultivations. It is also possible to calculate the differential subsidy ΔE, if a cultivation area of 361,644 × 1000 m^2 (see Table 18) is replaced. The results are presented in Table 21.

From the data in Table 21 it can be seen that in the case of tobacco, cotton and corn, the differential subsidy is negative, that means that no additional subsidy is needed.

Finally, Fig. 6 presents the sensitivity analysis of the differential subsidy as a function of three parameters (efficiency

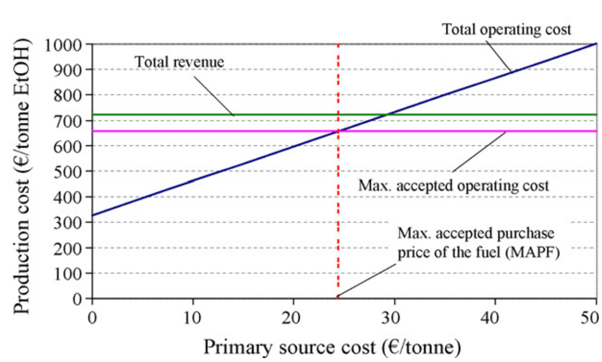


Fig. 5. Diagram of the viability of a bioethanol plant.

Table 20
Calculation of the required subsidy, for the replacement six conventional cultivations (for bioethanol production)

To be replaced	$RC_{conv} - RC_{en}$ (€/1000 m²)	E_{conv} (€/1000 m²)	$H \times I$ (€/1000 m²)	E_{en} (€/1000 m²)
Soft wheat	−51.00	15.56	40.30	20.47
Hard wheat	−51.00	48.86	38.75	52.53
Tobacco	939.00	890.00	192.50	26.67
Cotton	64.00	146.00	112.00	93.27
Corn	29.00	51.28	118.85	39.03
Beet	54.00	47.00	168.69	49.62

Table 21
Calculation of the differential subsidy (ΔE) and the totally needed differential subsidy (ΔE_{tot}) for power production when replacing six conventional cultivations (for bioethanol production)

Cultivations to be replaced	Differential subsidy, ΔE (€/1000 m²)	Total subsidy (€/year)		Totally needed differential subsidy, ΔE_{tot} (€/year)
		Conventional cultivations	Sweet sorghum	
Soft wheat	4.91	5,627,486	7,402,989	1,775,503
Hard wheat	3.67	17,670,886	18,997,926	1,327,040
Tobacco	−863.33	321,880,651	9,645,304	−312,235,347
Cotton	−52.73	52,802,893	33,732,103	−19,070,790
Corn	−12.25	18,546,112	14,116,624	−4,429,488
Beet	2.62	16,998,192	17,945,485	947,293

of the supply chain, improving of the efficiency of the process, selling price of bioethanol). From this figure it can be seen that for 10% rise of the selling price of bioethanol (from €650 to 715 tonne^{-1}) the needed differential subsidy is decreasing from €−12.25 to −39.02/1000 m².

Furthermore, if there is a process efficiency increase of 10% (e.g. with the development of more efficient enzymes) the needed differential subsidy decreases from €−12.25 to −23.61/1000 m².

If, finally, there is a 10% increase in the efficiency of the supply chain (from 70 to 77%), the needed differential subsidy increases from €−12.25 to −9.91/1000 m².

The improvement of the first two parameters, reduces the differential subsidy to (26.77 + 11.36=)€38.13/1000 m². Therefore, no subsidy is needed for the production of bioethanol.

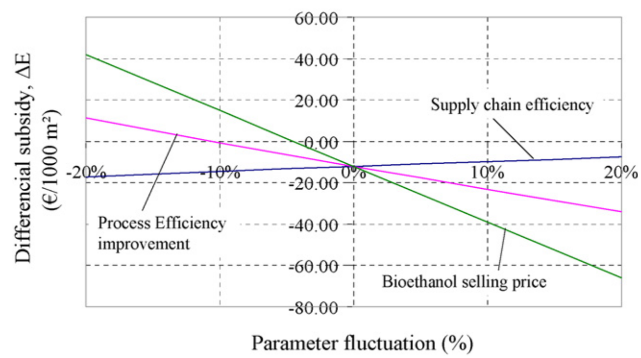


Fig. 6. Sensitivity analysis of the differential subsidy (ΔE).

6.4. *Biodiesel plant (40,000 tonnes/year) using sunflower as primary source*

For a typical plant of biodiesel production (capacity 40,000 tonnes/year) using sunflower as primary source, the main parameters concerning the availability of primary source are presented in Table 22.

Fig. 7 represents schematically a biodiesel production unit which includes the seed-oil conversion unit (extraction of gross oil), the semi-refinery (where the neutralization of the gross oil takes place) and the biodiesel unit (where the esterisation of the neutralized oil with methanol takes place).

This production direction is followed by a lot of investment plans in Greece for biodiesel production. It should be remarked that the produced glycerine (by-product of the unit) has an 80% purity and is provided to the glycerine market (cosmetics, soap

Table 22
Primary source availability for a typical biodiesel plant

Parameter (unit)	Values
Cultivation efficiency (kg seed/1000 m²)	350
Conversion efficiency (seed to oil) (%)	40.00
Conversion efficiency (seed to cake) (%)	40.00
Conversion efficiency (oil to biodiesel) (%)	96.15
Supply chain efficiency (%)	70.00
Product efficiency (biodiesel) (kg biodiesel/1000 m²)	134.6
Needed area (×1000 m²)	424,490
Total yearly quantities of primary sources provided to the unit[a] (tonnes/year)	104,000
Total yearly primary source quantities[b] (tonnes/year)	148,571
Specific efficiency of sun oil (kg oil/1000 m²)	98.00
Specific efficiency of the cake (kg/1000 m²)	94.23
Specific net efficiency of biodiesel (kg biodiesel/1000 m²)	94.23

[a] It corresponds to the provided primary sources to the biodiesel unit for which producer is paid from the investor.
[b] It corresponds to the produced biomass quantities from the producers and the totally cultivated area of sunflowers for biodiesel (taking into consideration 70% efficiency of the supply chain).

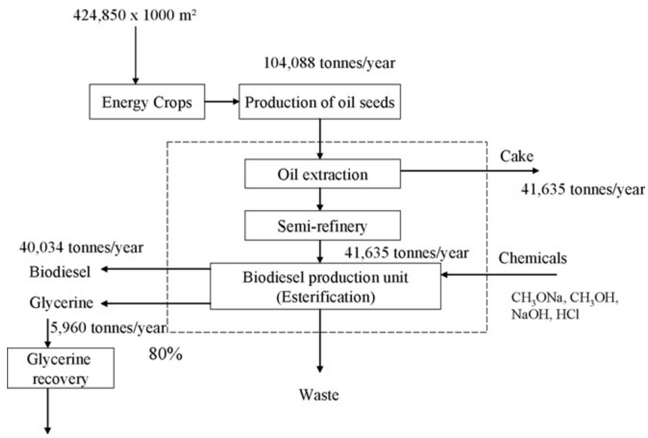


Fig. 7. Scheme of a biodiesel production unit from sunflower.

production, etc.). The non-treated glycerine can also be used in Central Digestion Units. The selling price of the non-treated glycerine (crude glycerine) shows a great fluctuation. More specifically, the prices ranged from €340 tonne^{-1} in June 2004 to €190 tonne^{-1} in January 2005, due to the high biodiesel production in Europe. The prices are expected to be stabilized to the level of €200 tonne^{-1} of pure glycerine (efficiency ≈ 80%) [29].

The investment cost of a typical biodiesel production unit is calculated as follows:

- For the biodiesel unit (electrical and mechanical equipment) the Specific Investment Cost is estimated at €≈570 tonne^{-1} biodiesel/year, or the total investment cost is (570 × 40,034=)€22,820,000.
- For the seed-oil conversion unit and the semi-refinery (electrical and mechanical equipment), the Specific Investment Cost is estimated at €≈100 tonne^{-1} of oil producing seeds/year [30], or the total investment cost is (100 × 104,088=)€10,409,000.
- For the civil engineering costs and the other costs (energy potential studies, consultancy, etc.) the investment cost is estimated at 12 and 2%, respectively, to the total investment cost of the electrical and mechanical equipment cost (about €4,000,000 and 700,000, respectively).

The total investment cost of the whole unit is around €38,000,000. The needed investment is estimated at 25% and the possible subsidy at 40%.

Table 23
Operating cost of a typical biodiesel unit

Operating cost parameter	€/tonne	€/year
Operating expenses of the seed-oil production unit[a]	64[c]	6,661,651
Operating expenses of the biodiesel unit[b]	77.35[d]	3,096,722
Yearly total operating cost		9,758,373

[a] Related to the quantity of the seeds provided to the unit.
[b] For the totally produced biodiesel quantities.
[c] The operating cost of the independent sunflower-oil unit is around €80 tonne^{-1} of oil producing seed, however in the case of the combination with the biodiesel unit, there is a decrease of 20%.
[d] The price is at €/tonne biodiesel [31].

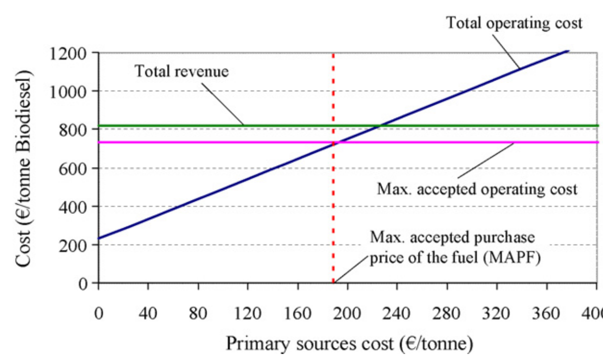


Fig. 8. Diagram of the viability of a biodiesel plant.

The operating cost (without fuel cost) of a typical biodiesel unit is presented in Table 23. The operating cost of the seed-oil (without fuel cost) is estimated at €≈75–85 tonne^{-1} of oil producing seeds [30]. However, due to the combination of the oil production unit and the biodiesel unit it is expected that this cost will be reduced at around 20% due to economies of scale.

As mentioned before, the prices of the products and by-products are for biodiesel €≈650 tonne^{-1} biodiesel [4] for cake €≈150 tonne^{-1} cake [32] and for glycerine €200 tonne^{-1} of pure glycerine.

The above data is inserted to a typical economic model where it is calculated that the MAPFP in this scenario is equal to €188.53 tonne^{-1}. The viability of the specific investment plan is presented in Fig. 8.

Since MAPFP is calculated and considering the efficiency data (Table 1) and the transportation cost of sunflower (Table 5), it is calculated that, according to Eq. (4), in order to have an IRR = 15%, the procurement cost of sunflower from the field cannot exceed the price of A = €43.78/1000 m^2.

Table 24
Calculation of the needed subsidy, after replacing six conventional cultivations (For biodiesel production)

To be replaced	$RC_{conv} - RC_{en}$ (€/1000 m^2)	E_{conv} (€/1000 m^2)	$H \times I$ (€/1000 m^2)	E_{en} (€/1000 m^2)
Soft wheat	−1.80	15.56	40.30	5.82
Hard wheat	−1.80	48.86	38.75	37.88
Tobacco	988.20	890.00	192.50	12.02
Cotton	113.20	146.00	112.00	78.62
Corn	78.20	51.28	118.85	24.39
Beet	103.20	47.00	168.69	34.97

Table 25
Calculation of the differential subsidy (ΔE) and the totally needed differential subsidy (ΔE_{tot}) for power production when replacing six conventional cultivations (for biodiesel production)

Cultivations to be replaced	Differential subsidy, ΔE (€/1000 m^2)	Total subsidy (€/year)		Totally needed differential subsidy, ΔE_{tot} (€/year)
		Conventional cultivations	Sun flower	
Soft wheat	−9.74	6,610,669	2,473,448	−4,137,221
Hard wheat	−10.98	20,758,182	16,094,146	−4,664,035
Tobacco	−877.98	378,116,697	5,107,520	−373,009,177
Cotton	−67.38	62,028,132	33,402,544	−28,625,588
Corn	−26.89	21,786,319	10,360,028	−11,426,291
Beet	−12.03	19,967,960	14,857,832	−5,110,128

Based on the data for the production of sunflower (Table 1) and the cultivations to be replaced (Table 11) the needed subsidy (E_{en}) is provided in Table 24.

Table 24 shows that the needed subsidy E_{en} is lower than the present subsidy for all cultivations. The differential subsidy for total sunflower cultivation area of ≈424,490 × 1000 m^2 is presented in Table 25.

It can be seen that in all cases a negative differential subsidy appears. So lower subsidies are needed in the case in which the conventional cultivations are replaced with sunflowers.

Finally, Fig. 9 shows the sensitivity analysis of the differential subsidy as a function of three parameters (efficiency of the supply chain, improving of the efficiency of the process (oil production), selling price of biodiesel). From this figure it can be seen that if the selling price of biodiesel increases 10% (from €650 to 715 $tonne^{-1}$), the differential subsidy decreases from €−26.89 to ≈−33.00/1000 m^2.

If the process efficiency increases 10% (efficiency of the seed to oil from 40 to 44%), the differential subsidy decreases from €−26.89 to −31.49/1000 m^2.

Finally if the efficiency of the supply chain increases 10% (from 70 to 77%) the needed differential subsidy decreases only moderate (from €−26.89 to ≈−27.11 $tonne^{-1}$). The improvement of the first two parameters (of the biodiesel price and the efficiency of the process), leads to a total decrease of the differential subsidy of sunflower, around (6.11 + 4.60=) €10.71/1000 m^2, making the combined units of oil and biodiesel production from sunflower feasible.

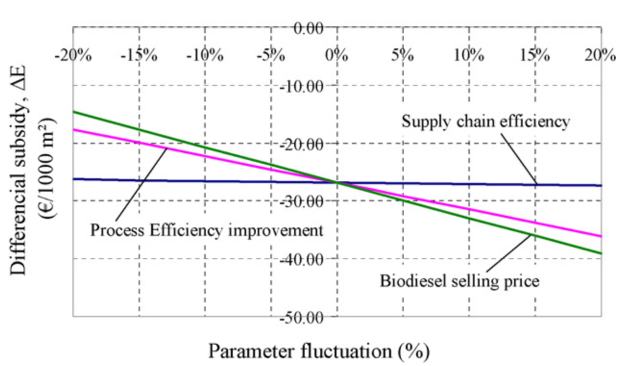


Fig. 9. Sensitivity analysis of the differential subsidy (ΔE).

6.5. Pellet production unit (≈44,000 tonnes/year) from fiber sorghum

For a typical unit of pellet production (capacity 44,000 tonnes/year) using fiber sorghum as primary source, the main parameters concerning the availability of primary source are presented in Table 26. The data is based on information from the German pellet company KAHL [33] for a unit of similar capacity [12].

Tables 27 and 28 present the total investment cost as well as the operating cost for the pellet unit.

Thek and Obernberger [34] present a SOC-FC of around €45 $tonne^{-1}$ for a unit of a capacity of 24,000 tonnes of pellets a year. The present approach, regarding also the capacity difference of the two units is satisfactory.

In central Europe, the selling price of pellets is around €170 $tonne^{-1}$. This price is given in mature markets (Germany, Austria), where there is a supply and selling system of the pellets and a high demand but also technical support for pellet fired boilers. Therefore it is expected that the starting pellet price in Greece will be much lower and after some years it will reach the level of central Europe. In the present study a selling price of €130 $tonne^{-1}$ is set.

The above data is inserted to a typical economic model and the MAPFP in this scenario is calculated equal to

Table 26
Primary source availability for a pellets production unit

Parameter (unit)	Values
Capacity of the treatment equipment (kg/h)	7,355
Availability of the equipment (%)	92
Operation of the unit[a] (days/year)	310
Operation shifts every day	3
Installed power capacity (kW_e)	892
Operating hours every year[b] (h/year)	5,985
Supply chain efficiency (%)	70
Pellets capacity (tonnes/year)	44,021
Total yearly quantities of primary sources provided to the unit (tonnes/year)	76,862
Needed primary sources (in the field) (tonnes/year)	109,803
Efficiency of fiber sorghum (dry tonnes/1000 m^2/year)	2.60
Humidity of fiber sorghum (%)	30
Needed cultivation area (×1000 m^2)	29,562

[a] Week operation of the unit with the exception of Sundays and very important holidays (except 55 days a year).
[b] 7 working hours in each shift.

Table 27
Total investment cost for a typical large pellets production unit

Parameter (unit)	Values
Specific Investment Cost (€/tonne)	144
Plant size (tonnes of pellets/year)	44,021
Total investment cost (€)	6,339,039
Needed investment[a] (€)	1,584,760
Needed subsidy[b] (€)	2,535,615
Credit (€)	2,218,664

[a] The needed investment is the 25% of the total investment cost (data from the company KAHL).
[b] The expected subsidy corresponds to the 40% of the total investment cost.

Table 28
Total operating cost (€/year) and Specific Operating Cost (€/tonne) for a pellets production plant [12]

#	Operating cost parameter	%	€/year
A	Personnel	20.49	316,650
B	Operation and maintenance (O&M)	20.51	316,952
C-1	Consumables (electricity consumption)	39.39	608,782
C-2	Consumables (diesel consumption)	5.18	80,000
D	General expenses	3.07	47,498
E	Other consumables	2.26	35,000
F	Other costs	9.09	140,488
	Total operating cost (without fuel cost)	100.00	1,545,370
	Specific Operating Cost − Fuel Cost (SOC − FC) (€/tonne pellet)	35.11	

€46.03 tonne^{-1}. The viability of the specific investment plan is presented in Fig. 10.

Since MAPFP is calculated and considering the efficiency data (Table 3) and the transportation cost of fiber sorghum (Table 5), it is calculated that, according to Eq. (4) in order to have an IRR = 15%, the procurement cost of fiber sorghum from the field cannot exceed the price of A = €91.12/1000 m^2.

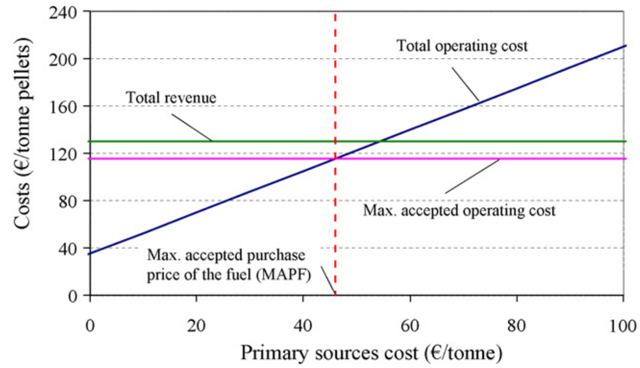


Fig. 10. Diagram of the viability of a pellet production plant.

Based on the data for the production of fiber sorghum (Table 3) and the cultivations to be replaced (Table 11) the needed subsidy (E_{en}) is presented Table 29.

In Table 29 it can be seen that the needed subsidy is lower than the present for the replacement of all six conventional cultivations. For the replacement of two cultivations (soft wheat and tobacco) almost no subsidy of fiber sorghum for pellet production is needed. It is possible to calculate the differential subsidy ΔE, if a cultivation area of 29,562 × 1000 m^2 (see Table 26) is replaced. The results are presented in Table 30.

From the data in Table 30 it can be seen that in the case of replacement of the conventional cultivations with fiber sorghum for pellet production, a negative subsidy for all the cases is resulted. That means that lower subsidies are needed for the same cultivation areas.

Finally, Fig. 11 shows the sensitivity analysis of the differential subsidy as a function of three parameters (efficiency

Table 29
Calculation of the needed subsidy, after replacing six conventional cultivations (for pellets production)

To be replaced	$RC_{conv} - RC_{en}$ (€/1000 m^2)	E_{conv} (€/1000 m^2)	$H \times I$ (€/1000 m^2)	E_{en} (€/1000 m^2)
Soft wheat	−40.80	15.56	40.30	−2.52
Hard wheat	−40.80	48.86	38.75	29.54
Tobacco	949.20	890.00	192.50	3.68
Cotton	74.20	146.00	112.00	70.28
Corn	39.20	51.28	118.85	16.05
Beet	64.20	47.00	168.69	26.63

Table 30
Calculation of the differential subsidy (ΔE) and the totally needed differential subsidy (ΔE_{tot}) for power production when replacing six conventional cultivations (for pellet production)

Cultivations to be replaced	Differential subsidy, ΔE (€/1000 m^2)	Total subsidy (€/year)		Totally needed differential subsidy, ΔE_{tot} (€/year)
		Conventional cultivations	Sweet sorghum	
Soft wheat	−18.08	459,991	−74,437	−534,428
Hard wheat	−19.32	1,444,419	873,333	−571,086
Tobacco	−886.32	26,310,537	108,849	−26,201,687
Cotton	−75.72	4,316,111	2,077,705	−2,238,405
Corn	−35.23	1,515,960	474,335	−1,041,625
Beet	−20.37	1,389,433	787,307	−602,126

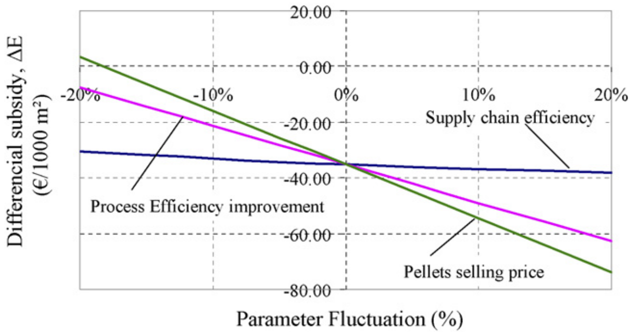


Fig. 11. Sensitivity analysis of the differential subsidy (ΔE).

of the supply chain, improving of the efficiency of the process, selling price of the pellets). From the diagram it can be seen that 10% rise of the selling price of pellets (from €130 to 143 $tonne^{-1}$) leads to a decrease at the needed differential subsidy from €−35.23 to −54.56/1000 m^2.

Furthermore, if there is a process efficiency increase of 10% (e.g. with more efficient drying process in the unit) the needed differential subsidy decreases from €−35.23 to −49.01/1000 m^2.

If, finally, there is a 10% increase in the efficiency of the supply chain (from 70 to 77%), the needed differential subsidy decreases from €−35.23 to −36.79/1000 m^2.

The improvement of all parameters reduces the differential subsidy to (19.33 + 13.78 + 1.56=)€34.67/1000 m^2.

7. Conclusions

In this paper the main costs for biomass use have been discussed. Furthermore, four investment plans have been presented and analysed.

The main conclusions from these investment plans are the following:

- In most of the cases, the subsidy for the cultivation of energy crops should be much higher than the present one of €4.50/1000 m^2.
- Fiber sorghum for power production is non-profitable since it needs high subsidy. Therefore an increase of the selling price of electricity from biomass is needed. On the other hand, fiber sorghum used for the production of solid biomass fuel (pellets) is the most profitable from the four energy crops examined.
- Sweet sorghum (almost in all cases of replacement of conventional cultivations) needs lower subsidies than the conventional cultivations, without the decrease of the profit of the farmers.
- Sunflower (for its exploitation with a combined unit producing oil and biodiesel) needs, in all replacement cases lower total subsidy without decrease of the profit of the farmers.
- Fiber sorghum for the production of pellets does not need any subsidy at all when replacing the cultivation of soft wheat and needs very low subsidy for the replacement of tobacco. In the other cases only low subsidy is needed without decrease of the profit of the farmers.

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